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A cross layer architecture for multicast and unicast video transmission in mobile broadband networks

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ABSTRACT

This paper focuses on the transport of Unicast and Multicast traffic in the mobile broadband networks. The main objective is to allow video streaming applications to adapt its parameters according to 802.16MAC layer conditions and resource availability. For unicast traffic, we propose a cross layer optimizer, named XLO, between scalable video streaming application and IEEE 802.16 MAC layer. XLO uses the existing service flow management messages exchanged between a base station (BS) and a subscriber station (SS) and make them available to the video streaming application via a specific XLO interface. We implemented the XLO in the QualNet simulator and performed extensive simulations using a personalized scalable video traffic generator, capable of streaming video with different data rates and quality levels. We also introduce an enhanced admission control function at the BS that takes into account video adaptability property. The simulation results show the effectiveness of our XLO mechanism for delivering better quality of service. For multicast traffic, we propose a new solution based on superposition coding and make use of scalable video coding in order to optimize the network resources.

1. Introduction

Along with the prevalence of the Internet today and the diversity of technologies supporting multimedia services, wireless technologies continue to progress towards providing more bandwidth and more coverage with the best quality of service and experience for the users.

IEEE 802.16 (WiMAX) (IEEE Std 802.16, 2004; IEEE Std. 802.16e, 2006), is a broadband, high data rate wireless technology intended to support multimedia applications such as real-time video streaming and VoIP. In order to perform efficiently, real time applications require strict resource reservation, namely bandwidth guarantees and bounded transmission delay, jitter and loss rate. However, the availability of the network resources is subject to the network status notably at the physical (PHY) and Medium Access Control (MAC) layers. In response to the lack of resources, video streaming applications should ideally adapt their data rate according to changes in network status observed at the PHY and MAC layers. This process is called awareness and is used in many cross-layer optimization mechanisms. Cross-layer design is an ongoing research topic aimed at increasing the Quality of Service/Experience (QoS/QoE) by performing coordinated actions across different network layers and, thus, violating the ISO/OSI protocol layeing and isolation model.

Accordingly, this paper introduces two mechanisms for respectively handling unicast and multicast video transport in mobile broadband networks. For unicast traffic, we propose a cross-layer optimizer, named XLO, which facilitates the information exchange between streaming applications and IEEE 802.16 MAC layer necessary to perform rapid and accurate video quality adaptations according to physical network conditions. Further, we developed a video quality aware admission control function at the Base Station (BS) aiming at guaranteeing the expected QoS. The objective is to exploit the scalability property of video streams and adapt the video quality to the available resources. For multicast traffic, we propose a new solution that optimizes the delivery of scalable video streams based on superposition coding so as to provide the best compromise between resource availability and network status.

The rest of this paper is organized as follows. Section 2 discusses the related work. Section 3 provides useful background and Section 4 describes the system architecture and the targeted scenario. Performance evaluations are presented in Section 5 and the conclusions in Section 6.

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2. Related work

Most previous works on cross layer optimizations in WIMAX networks focused on PHY and MAC layer interactions and do not explicitly consider the application layer (APP) performance. Mai et al. (2007, 2008) propose a cross layer framework to integrate layer 3 and layer 2 QoS. They introduce a fragment control mechanism which en-queue all fragments coming from different IP packets in the same buffer. They also propose a remapping scheme for better buffer utilization allowing a low frame-dropping ratio. Noordin and Markarian (2007) propose a cross layer optimizer between MAC and PHY layer. Their solution collects parameters like channel condition information, bandwidth requests and queue length from both layers and return optimized parameters back to the two layers.

In Triantafyllopoulou et al. (2007) and Li et al. (2009), the application layer is included in the cross layer optimization along with the MAC and PHY layers. Optimization is performed at the Base station (BS), which delivers video traffic to the Subsriber Station (SS). Triantafyllopoulou et al. (2007) utilize information provided by the PHY, MAC and APP layers to improve system performance. The main idea is to adapt and adjust modulation in the MAC layer and the data rate of the video streaming application depending on channel conditions. They introduce new management messages to inform the SS about the video data rate. Li et al. (2009) conduct a performance evaluation study of a cross layer approach for multiuser H.264 video transmission in wireless networks. Three steps are defined: abstraction of parameters from the APP and Radio Link layers; selection of optimized parameters; and their distribution to corresponding layers. A cross layer algorithm is applied at the beginning of each frame for all users simultaneously which adds a significant overhead.

Our work considers cross layer optimization between application and MAC layers at the server-side in the SS and not at the BS as in Triantafyllopoulou et al. (2007) and Li et al. (2009). Moreover, in our approach, we do not add any new management messages but rather exploit existing MAC management messages. Finally, to reduce the computation overhead, our optimization is performed only at the beginning of a video streaming session or during the life-time of a session if any changes are detected in the MAC layer conditions.

3. Background and preliminaries

This section provides relevant background and preliminaries pertaining to QoS support and service flow management in IEEE802.16, heterogeneous clients support in WiMAX, and hierarchical coding for multicast support.

3.1. QoS design & service flow management in IEEE 802.16

Each packet passing through the IEEE 802.16 MAC interface belongs to a service flow (SF) identified by a connection identifier (CID). A SF is a unidirectional flow of packets providing a particular QoS assurance in terms of a set of QoS parameters such as latency, jitter and throughput. A SF may be created, changed or deleted using the following MAC management messages, essential for our cross-layer optimizer.

3.1.1. Dynamic service flow add message (DSA)

Creation of a SF is initiated by either the SS or the BS. If SS is the initiator, the message contains reference to the concerned SF, QoS parameter sets or service class name. The BS responds by DSA_RSP message indicating the acceptance or rejection of the request. The rejection message may contain extra information such as unsupported parameters or wrong values. When the BS is the initiator, the DSA-REQ message contains SF identifier (SFID), CID and active or admitted QoS parameters. The response of the SS is the same as in the first case.

3.1.2. Dynamic service flow change message (DSC)

After its creation, a SF can be modified via the DSC-REQ message. The modification includes admitted and active QoS parameters. Changes are done when both admitted and active parameters are replaced. In fact, if only admitted parameters are included in the message, active parameters will be set to null and SF will be deactivated. When both parameters are inserted in the message, admitted sets are verified first by the admission control mechanism and then the activated sets to ensure that it is a subset. If successful, changes take place in the SF; otherwise, the SF become unchanged and continues performing with existing parameters.

3.1.3. Dynamic service flow delete message (DSD)

A SF is deleted from BS or SS through DSD_REQ message. Moreover, a SF may be deleted implicitly when errors or mistakes occur. The SF management messages will be used in our approach to help XLO fix the optimized video streaming parameters and consequently provide better delivered quality of service. Details of our approach are described in the next section.

3.2. Supporting heterogeneous clients in WiMAX

The transmission of an IP video stream would be significantly facilitated if the clients share the same radio conditions. However, due to the inherent characteristics of the wireless medium in real world scenarios, the mobile clients who are attached to a WiMAX BS have heterogeneous capabilities. Figure 1 shows this phenomenon with different users supporting 64QAM, 16QAM, and QPSK coding.

The closer the SSs are to the BS, the higher the bandwidth they have and better the quality of experience for the user. On the other hand, the SSs which are not close enough to the BS will not obtain the needed resources to meet the video streaming requirements. To overcome this, adaptation policies could be enforced at the video server-side to manage the network resources efficiently and hence provide the appropriate user QoE. In this case, multicasting cannot be supported because of the heterogeneity of user

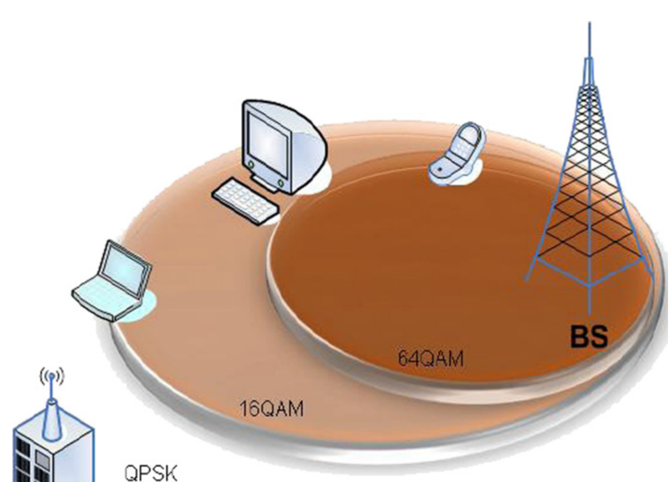

Fig. 1. Low increased to high quality video data rate during transmission.

profiles present in the cell. Below, we discuss the limitations of IP multicast through different cases:

- Case 1: The transmission of a video stream with the highest quality to satisfy the most favoured client, with enough resources. In this case, all other users who do not meet the criteria of the video stream in terms of resources will fail to receive the video stream with a correct quality (due to signal attenuation).
- Case 2: The transmission of a video stream with the lowest quality to satisfy all the users. In this scenario, users with higher bandwidth are jeopardized and will receive a lower quality video.
- Case 3: Transmission of a video stream with an acceptable quality for the majority of the users. This increases the number of satisfied users with the perceived video quality but does not solve all the issues. Some users with good channel conditions will not receive the video at the best possible quality; others will not receive any video.
- Case 4: Transmission of a video stream several times with a different degree of quality. The video server may, depending on the profiles of its users run multiple video streams with different quality (minimum, average and maximum). This solution can satisfy a greater number of users. If the video profiles of different users are very close, the number of video streams to be transmitted is reduced. In contrast, if the diversity of profiles is important, the number of video streams cannot solve the problem. Despite the simplicity, this solution has the biggest disadvantage of increasing the bandwidth required and the resources necessary to transport different qualities of the same video stream.

None of the above solutions handles the problem of diversity in terms of network resources (the far we are from the BS, the less resource are available). Depending on which case, some users will experience a degradation of their QoE, the network resources will not be managed effectively, or some users will be ineligible for service. Ideally, the perceived video quality by each user should correspond to its capabilities and the available resources. The ultimate solution should take into account all these constraints. In this perspective, recent developments of video coding supporting the heterogeneity of user profiles and network environments suggest hierarchical coding of SVC (Scalable Video Coding) techniques for multicast services support. Indeed, SVC appears to be the most appropriate video coding solution that meets the requirements discussed above.

3.3. SVC coding

Unlike many coding schemes that generate a single video stream with a single layer, the SVC generates multiple streams with multiple hierarchical levels: the basic layer (BL: Base layer) and one or more enhancement layers (EL: Enhancement layer). The base layer is sufficient for decoding, but the decoding of enhancement layers require decoding of the base layer and all depending enhancement layers. Hierarchical levels can be constructed in three dimensions: temporal, quality (SNR) and spatial as depicted in Fig. 2.

- The time dimension refers to the number of frames per second (frame rate). The base layer consists of I and P frames and the enhancement layers are composed of B frames inserted between images I and P.
- The spatial dimension refers to different image sizes. The upper layers provide a larger image.
- The quality dimension SNR is the image quality. The upper layers allow a finer quality of the image with more precision.

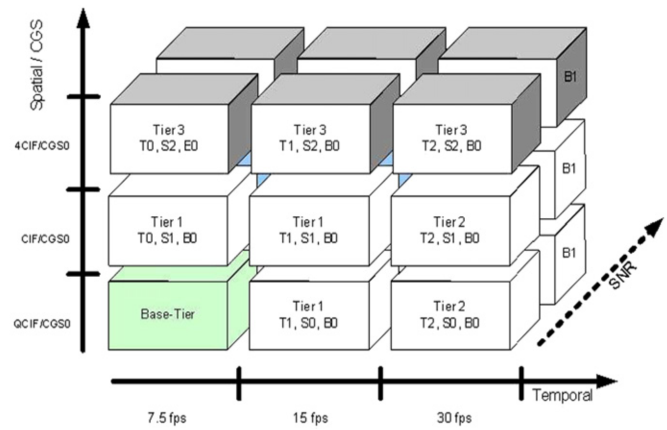

Fig. 2. SVC hierarchical level.

3.4. Hierarchical coding for multicast support

There are several studies devoted to the use of hierarchical coding techniques for multicast video transmission. We describe below two prominent proposals upon which our solution is constructed.

The SVSoA approach is defined in Neumann and Roca March (2003). The authors present a solution for streaming video using hierarchical multicast IP. By using the Asynchronous Layered Coding (ALC) protocol (Luby et al., 2002), SVSoA guarantees the scalability vis-à-vis the heterogeneity of the users and the reliability. However, the ALC protocol is considered as a reliable multicast transport protocol only and was not primarily designed for real-time transmissions. The authors combine hierarchical video coder with the ALC protocol. Specifically, the video server splits the video into segments of equal duration. Each segment is composed of several blocks so that each block represents the base video layer or an enhancement layer. The transmission of each block is performed independently in an ALC session. Thus, each video layer is transmitted in a different multicast group. Upon receipt, each client begins by retrieving data from the first ALC session which contains the base video layer. Then, before the end of the segment duration, the client switches to the session that corresponds to the ALC video layer enhancement. This process is repeated for all enhancement layers. The authors considered a session for the base layer and another for a single enhancement layer. SVSoA uses a fixed duration segment of 60 s, and as the reception of the layers is sequential, the playback can begin before the full acquisition of the segment. Thus, a higher latency is observed compared to a conventional architecture where the segment size is the size of an image (1/25 s). According to the authors, SVSoA solution is valid for all hierarchical video coding schemes. The drawback of this solution lies in the increasing number of active ALC sessions. Indeed, the server must send all the video layers and thus create a large number of ALC sessions even if the user will only receive the base layer video. The second issue not addressed in this approach concerns the heterogeneity of the receivers. Finally, we must ensure that the duration of the video segment will allow the user to receive the maximum enhancement layers in addition to the base layer.

She et al. (2008, 2009) propose a Cross-Layer Architecture for IPTV video transmission in a WiMAX network. The proposed solution aims at finding a compromise between an application such as hierarchical video coding MDC and the radio channel condition of the users. Then, a Cross-Layer approach is adopted. This solution takes into consideration the features of the MDC video applications and offers a modulation scheme for optimal resource allocation to maximize video quality even under the worst channel conditions. She et al. (2007) propose a new modulation scheme for WiMAX networks, allowing a better multicast transmission. Each multicast stream is transported differently depending on the required quality. The basic video layers are streamed using a BPSK modulation scheme and for the enhancement layers a better modulation such as 16QAM are used. This way, a receiver can get the basic video quality by decoding partially multicast packets over a modulated BPSK channel when the channel condition is deteriorating, or get the best video quality from all streams (both BPSK and 16QAM channel). A modification to the MDC coding is introduced by the authors by applying a proper protection scheme to the MDC base layer. This modification is essential to use the proposed coding technique. Indeed, while protecting the packet modulated with BPSK is not necessary, for 64QAM modulation, many losses can occur and extra protection will provide coding reliability of the transmission.

The above selected techniques for multicast video transmission take into account the hierarchical coding of video streams, the users diversity (distance form the BS) and radio channel access. They served as a basis for defining our multicast architecture using SVC coding. Our proposed architecture is described in the following section.

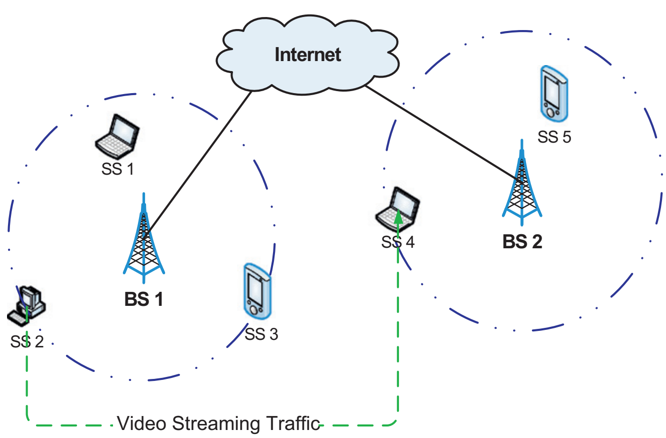

Fig. 3. System architecture.

4. Target scenarios and system architecture

4.1. Unicast services support

We focus on scenarios for providing unicast services to users in which different SSs share their video in real time. Use cases here include video conferencing, video surveillance and P2P video delivery where unicast streaming is appropriate. Our approach consists in optimizing video streaming applications initiated by SSs in the Uplink channel. Figure 3 shows a video streaming traffic between 2 SSs associated with different BSs (BS1 and BS2).

Our proposed design consists of an adaptation mechanism at the video streaming application jointly with cross layer mechanism between MAC and Application layers. The adaptation occurs at the server-side, i.e., the owner of the video content. Our design for the protocol stack interactions is illustrated in Fig. 4. We can see the reference model essentially for MAC and PHY layers as defined in IEEE 802.16d standard (IEEE Std 802.16, 2004) and the XLO. The XLO makes available the SF management messages (DSA, DSC, and DSD) to the video streaming server-side, which in turn, makes the video parameters available to XLO later from the beginning of the streaming session. The CPS (Common Part Sub layer) provides the core MAC functionality of system access, bandwidth allocation and connection establishment. In particular, CPS is responsible for SF management. Thus, the XLO interacts with CPS sub-layer and video streaming server-side application layer.

4.1.1. Cross layer optimization algorithm

The devised cross layer optimization algorithm consists of 3 steps. First, we collect information from CPS sub-layer. Second, this information is analyzed and a decision is made at the XLO. Finally, we apply the adaptations by enforcing the new video parameters at the video streaming server-side.

4.1.2. Information collection

As mentioned in Section 3.1, SFs are managed (added, changed and deleted) via DSA, DSC and DSD messages, respectively. Many messages are exchanged between SS and BS, and we are interested especially in DSA_RSP, DSC_REQ and DSC_RSP messages. The main idea consists in using existing management messages rather than adding new ones. Then, since our approach is implemented in the video streaming server-side, a copy of all SF

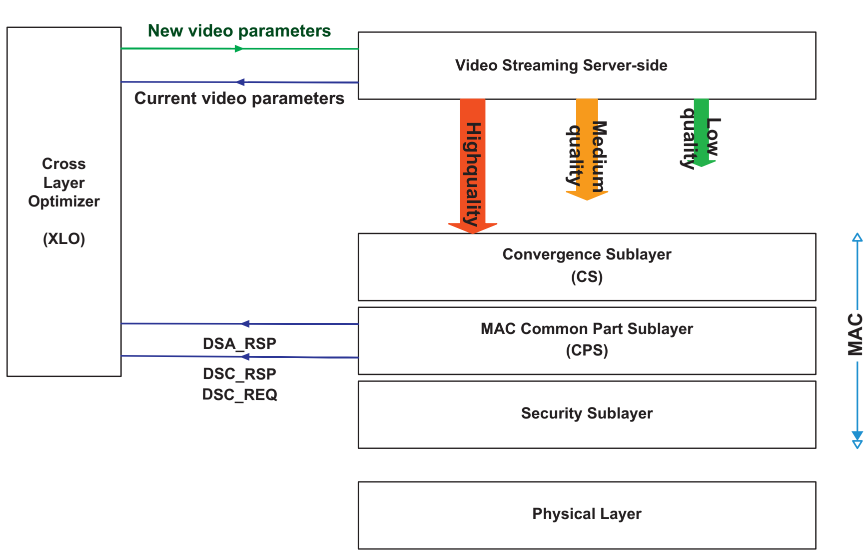

Fig. 4. Cross layer optimizer between MAC and application layer.

management messages initiated by the transmitter station or received from the BS will be collected by XLO.

4.1.3. Adaptation and modification

The collected SF management messages are first analyzed. These messages contain a positive response if the request is accepted and a negative response if the request is not totally accepted or rejected. If the request is not accepted, it indicates the unavailability of the required resources for the video stream. Hence, the video streaming application has to adjust its behavior in order to get a positive response in the next attempt. To this end, we modify the streaming parameters so as to adjust the video throughput. This procedure may be repeated until the video stream is accepted or we reach the minimum video quality supported with still a reject response. The selection of the minimum and maximum video quality levels is usually negotiated using existing signaling protocols such as SIP, RTSP or H323 and can be part of the service level agreement. This is however out of the scope of this paper. Once the request is accepted, the allocated resources and the time of acceptance are stored. Then, if the video stream performs correctly for a certain period, the XLO will increase the video data rate assuming that more resources are available. If the request is rejected, the video stream will continue using its current parameters. If accepted, the same process is repeated until we reach the maximum video quality. The algorithm describing this process is detailed below.

Algorithm 1 *XLO Algorithm*

```
Wait for SF management message or Time Out to increase
If SF management message then
    if Success then
        //no Optimization needed
        Start Time Out to Increase
    else if Reject then
        if minimum video quality not reached then
            Change Video streaming parameters
                (decrease data rate)
            go to 1:
        end if
    end if
end if
if Time Out to Increase then
    if maximum video quality not reached then
        Change Video streaming parameters
            (increase data rate)
        go to 1:
    end if
end if
```

The next subsection presents the sequence diagrams providing more details about the cross layer optimization operations and the exchanged messages between the entities involved in the optimization process.

4.2. Illustrating examples

When a new video is requested, the XLO allows us to identify the suitable video parameters that guarantee the acceptance of the corresponding SF at the MAC layer. During the video streaming, the changes occurring in the MAC layer conditions and consequently in the video throughput may force the service to be stopped or rejected. In the absence of our XLO, the video stream will abort if the SF parameters did not meet its QoS constraints. The XLO allows us to adapt video streaming data rate according to the fluctuation of the network conditions and hence avoids the SF rejection. Furthermore, our approach can be applied at the service request/invocation as well as during the life-time of the session or during service delivery. In the following, we will illustrate our approach through examples. We use the topology presented in Fig. 3 where in the SS2 station, we implement a video streaming server with XLO capability.

4.2.1. SS initiated DSA request message

When the MAC layer in SS2 receives a video, it initiates a DSA_REQ message with the desired QoS parameters and sends it to the BS1, which checks the integrity of the message and responds with a DSX_RVD (DSA or DSC received) message. Then, depending on the acceptance or rejection of the QoS parameters, BS1 sends DSA_RSP message with a success or reject code.

Figure 5 presents the sequence diagram where a new SF is rejected in the first attempt and accepted in the second attempt, thanks to XLO. In fact, once the SS receives a DSA_RSP reject message (step 5), it forwards it to XLO (step 6). The latter intercepts the message and commands the video streaming application to adapt its QoS parameters by reducing its video data rate (step 7 and 8). Then, a new video add request is initiated. The same procedure between BS1 and SS2 is performed. The request is accepted and the video streaming started.

After the acceptance of a new video flow, the channel conditions and availability of resources might vary. In this case, BS or SS should send a DSC request message in order to change service flow QoS parameters.

4.2.2. BS initiated DSC request message

The sequence diagram depicted in Fig. 6 shows a BS initiating a DSC request message (step 2). In fact, a BS should send a DSC request message once it is unable to meet the new SF QoS constraints. This might happen in two cases, when the required resources at the BS side are unavailable, or the QoS constraints cannot be satisfied by the link between BS1 and the SS4. Then, the BS1 sends a DSC request message to SS2 in order to adapt the SF parameters accordingly. Then, SS2 receives the request and changes the SF parameters (step 3).

4.2.3. SS initiated DSC request message

An SS must initiate a DSC_REQ message if it detects changes in the channel conditions. In this case, it requests BS1 to change the corresponding SF QoS parameters by increasing or decreasing the related video data rate. Once the BS1 receives DSC_REQ message, it replies by the DSX_RVD message if the request message is valid (step 4 in Fig. 7). Then, it checks if the new SF parameters can be supported and sends the DSC_RSP message to SS1 with a reject or success response.

If the request is rejected, SS1 will continue with its current parameters. If the request is accepted as mentioned in step 6, it sets up new SF parameters. Therefore, the XLO avoids the rejection of new video SF by adapting the video streaming parameters accordingly (steps 8 and 10).

4.3. Multicast services support

4.3.1. Mulicast group creation with SVC coding

With hierarchical coding, each user will receive at least the basic layer, and then, depending on the available bandwidth, it will receive a number of enhancement layers. With this distribution, we guarantee that each user will have the best possible

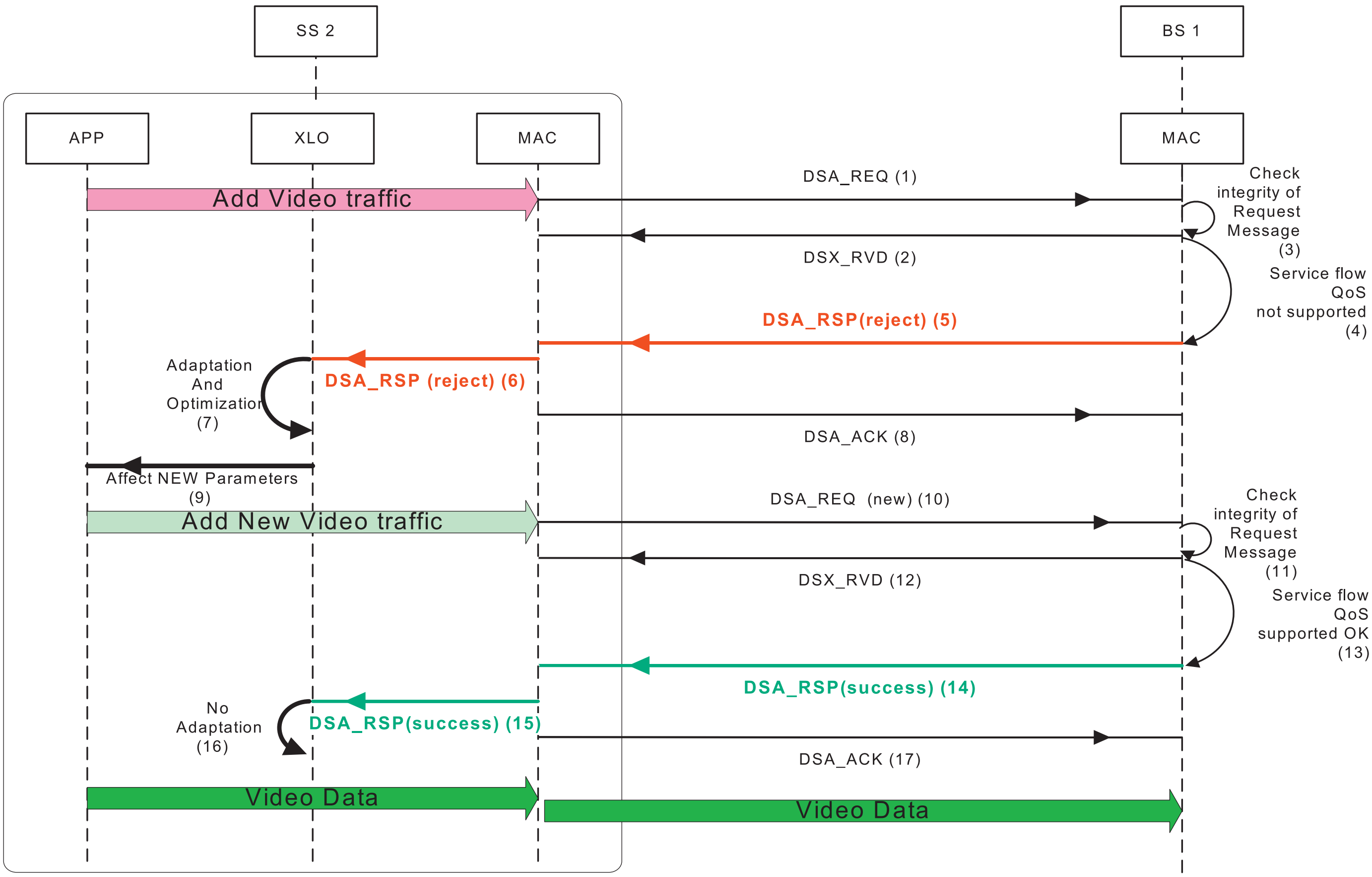

Fig. 5. SS initiated DSA request message.

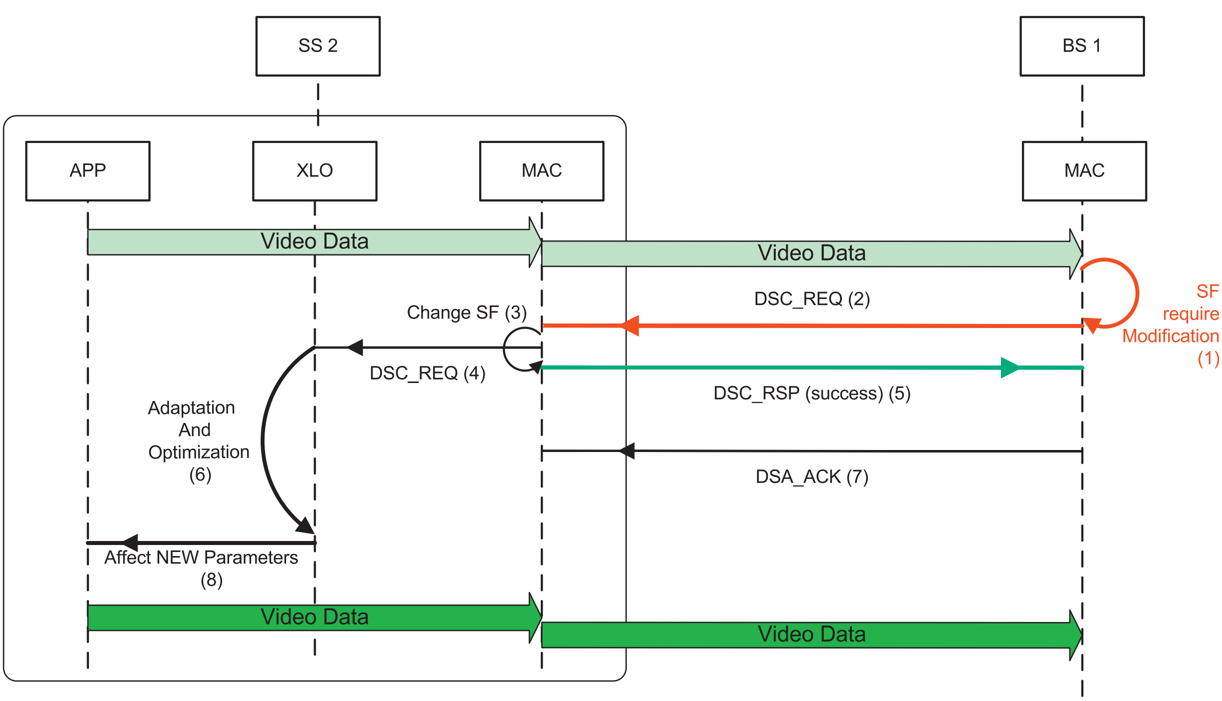

Fig. 6. BS initiated DSC request message.

video quality. To handle users heterogeneity, we define a cross-layer architecture that combines the features of the SVC hierarchy, the IP multicast transmission and physical layer characteristics of the WiMAX network. Transmitting a multicast SVC stream requires prior knowledge of available resources in the network to optimize its delivery. However, this knowledge is

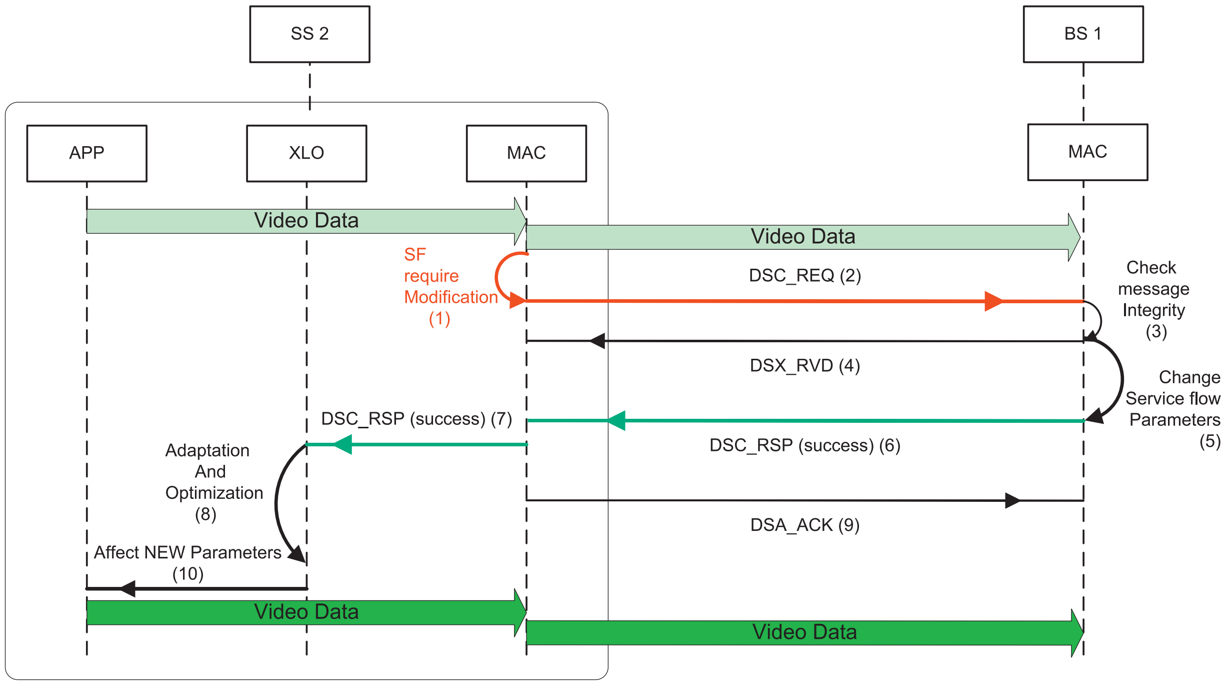

Fig. 7. SS initiated DSC request message.

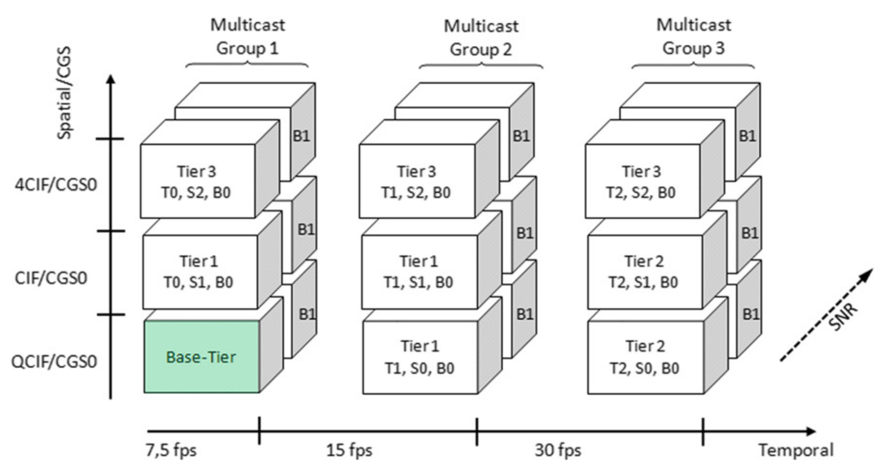

Fig. 8. Multicast group creation with SVC coding.

highly dependent on the type of traffic sent and the number of users in the cell. Several transmission scenarios are possible:

- Associate a multicast group with each video layer, one for the base layer and each enhancement layer. In this case, the number of multicast sessions is proportional to the number of layers. A multicast session is defined by a multicast address (IPv4 class D address).
- Associate a multicast group with several video layers. We may associate a multicast group to the base layer and the enhancement layers to one or several multicast groups. This solution is interesting and presents several alternative placements. Indeed, the choice of video layers can be grouped together according to several criteria.

Consequently, we opted for the generation of multicast groups according to the temporal axis which corresponds to the number of frames per second. Each multicast stream contains the highest SNR. This assumption is made mainly to simplify the simulation study and does not affect the design of our solution. An example of decomposition into several multicast groups is depicted in Fig. 8.

As a direct result of the SVC video encoder, the multicast groups created are complementary. In fact, according to the available bandwidth, a client should join the first multicast group, which represents or includes basic video layer to decode the enhancement layers. Then, according to its available bandwidth, the SS joins the second multicast group, and so on. To receive the highest video quality, a client should receive the data from all multicast groups. Thus, there is a direct correlation between the weight of multicast groups and the importance of the video layers they contain.

So far, we have explained how the application uses the SVC coding scheme, and how to create the multicast groups according to the video priority. In the following, we will describe MAC and physical layer related aspects, specifically how the proposed multicast architecture operates in a WIMAX network. We will also describe the proposed improvements, in particular at the radio level, to maximize the use of radio resources and to maximize video quality as perceived by the users.

4.3.2. Multicast transmission for WiMAX networks

To transmit a data stream, a request to add service flow should be sent to the base station even if it is the BS that must initiate the traffic. Then, admission control is performed. It is important to note that this procedure is valid for both unicast and multicast flows. More details are given bellow.

4.3.2.1. Admission control in WiMAX networks. Recall that admission control is a function that depends on the manufacturer, the IEEE 802.16 standard does not specify the scheduling algorithm, it only defines the various tools such as the signaling messages and the operation base. Indeed, the evaluation of available resources depends on the size of the frame to the PHY level, the frequency band, modulation and coding used. Thus, after fixing all these parameters, it would be feasible to calculate the number of slots a WIMAX physical station features. Recall also that a physical slot allocation consists of a rectangular symbol OFDM time and frequency. Suppose that the BS wants to send a data stream to one of the SSs of the cell, it begins by calculating the number of slots needed for physical flows. Then, the BS checks the availability of that number of slots and accepts or denies access to the stream. The SS will be informed of this decision via signaling messages and management of service flows. In particular, each SS receives the resource allocations in the MAP field at the beginning of each frame just after the preamble.

4.3.2.2. The DL_MAP message. At the beginning of each frame, the BS includes messages and DL_MAP UL_MAP that are broadcasted to all SSs in the cell. The DL_MAP contains the description of resource allocations for each SS for each data stream. The DL_MAP allows the SS to locate the data burst that shall receive. This burst is a part of the frame identified by a time range and frequency. Each burst is described in the form of a DL_MAP DL_MAP_IE. This provides the exact location within the frame.

According to IEEE 802.16, the DL_MAP field does not contain any information to describe the coding and modulation schemes used. Indeed, the modulation and coding are fixed only following the negotiations between the BS and SS. They can be updated when radio conditions change, the BS notifies the changes through the UCD and DCD fields which are sent periodically at the beginning of the frame. The value of the modulation and coding is used for all flows sent to the same SS. Thus, an SS may use two different modulations in the same frame for example.

A SS which can receive a 64QAM encoded data, but is capable of receiving data with more robust modulations such as BPSK or 16QAM, especially because UCD and DCD fields, and DL_MAP UL_MAP are all BPSK encoded so that all the SSs are lossless. The same is observed for the containment area dedicated to bandwidth demand by contention between all SSs. It is hence possible for the SS to receive data with different modulations that do not exceed the maximum negotiated with the BS.

Information containing the modulation scheme and coding used for any burst will be included in the corresponding DLMAP_IE. This is necessary for the implementation and comparison of the different approaches that we describe in the next paragraph.

4.3.3. Proposed architecture for supporting multicast services using SVC and superposition coding

In this section we study various possible topologies in WiMAX networks to support multicast services. There are several possible scenarios.

Initially, we consider the topology shown in Fig. 9. We have a server with a video encoder capable of transmitting video SVC flows in the form of several multicast sessions as it was presented in the previous paragraph. We assume that a flow is an SVC

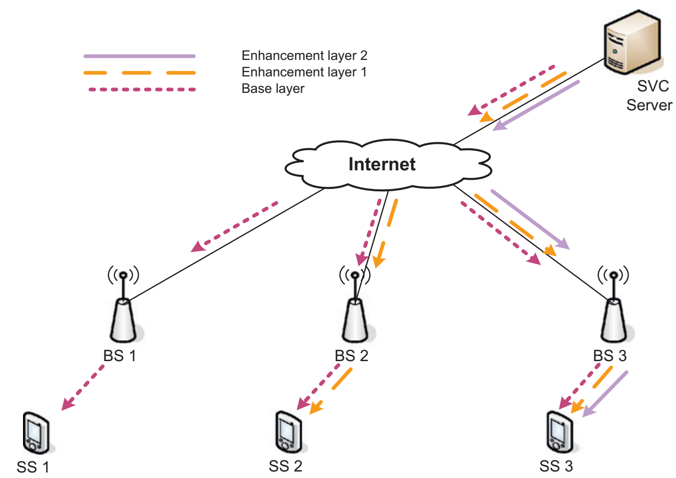

Fig. 9. Multi-cell architecture (multi-BS).

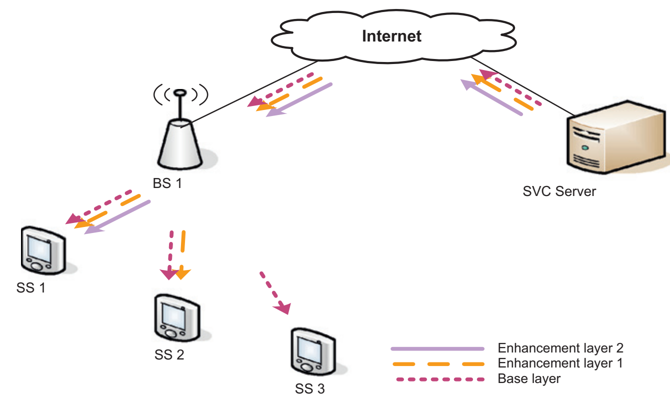

Fig. 10. Single cell architecture.

stream which consists of a base layer and two layers of improvements (layers are seen as groups providing each an enhancement of the final quality level). The multicast groups for the three quality levels are represented by small arrows in Fig. 9. We also assume that there are three WiMAX cells connected to the wired network. An SS of each cell connects to the server and requests the video stream in real-time.

According to their respective bandwidths from start to finish, each SS will be a member of one or more multicast groups. The SS1, for example, will be able to receive only the multicast session which is the base layer video stream of the SVC. This may be due to the unavailability of radio resources within its cell. The SS3, will be able to receive all three layers of video and will result in the highest available video quality. In this case, we note that the multicast streams are transmitted from the video server to the base station in each cell. Note that the third stream which corresponds to the second enhancement layer has not been sent to BS1 and BS2, while the first stream (Base Layer) was sent to all the BSs. Thus we conclude that the decomposition of the SVC flows into different multicast streams is sufficient, in particular for this kind of topology. An SS belonging to different cells will receive only the multicast stream which corresponds to its capabilities and the available resources. This also remains valid if different SSs belong to the same cell, provided they have the same radio characteristics. In this case, no additional resources are required.

We present now our approach within a single cell. Figure 10 depicts the same video server SVC and three SSs with different radio conditions belonging to the same BS.

We assume that the three SSs are at different distances from the BS so that the BS assigns to each SS a modulation scheme and different encoding. For example: 64QAM to SS1, SS2 and SS3 in 16QAM QPSK.

4.3.3.1. Single modulation scheme. For each SS that receives the best video quality, it must adhere to the three multicast groups and retrieve all the video layers. Once the multicast stream arriving at the BS, a request to create a new flow of service for each group and each SS is generated. The BS must duplicate each multicast stream since SSs have different modulation schemes. Thus the video base layer is transmitted three times within the same cell, once in QPSK, in 16QAM and once again in 64QAM. The same is done for the other two video layers. The BS will allocate the necessary resources for each new service flow. Obviously, in case radio resources are lacking, the BS will prioritize the transmission of the base layer and enhancement layers. Similarly, the most favoured SSs, closest to the BS in general, will be treated first. The scheduling mechanism of the BS must take into account these two criterions. In spite of its simplicity, this method has several disadvantages:

- Resource management is far from efficient. Indeed, the same data is encoded several times and such redundancy goes against the very principle of multicast transmission. Instead, this is a simultaneous transmission of the same video with different modulations and possibly with different qualities.
- The BS has a limited number of physical slots to allocate. Hence, some resource allocation requests cannot be satisfied.
- The SSs with better reception quality are those closest to the BS. The coding and modulation scheme used is less resource demanding, while the later SSs may reject the video stream due to a lack of resources.
- The SSs, supporting a less robust modulation are capable of decoding more robust modulation. Thus, these SSs can decode the same video stream as many times as a different modulation scheme is used.

To overcome these limitations, we propose, as a first step, a new resource allocation system to distribute the multicast stream for different modulations.

4.3.3.2. Multiple modulations scheme. The idea is to benefit from the fact that SS is capable of operating with a less robust modulation, and can also work with a more robust modulation. Indeed, by taking the topology described in Fig. 10, the multiple modulations mode is performed as follows:

- The base layer is modulated in QPSK, the burst of data containing the first service flow is visible for all the SSs without exception. Thus, the minimal video quality is already earned for all the SSs in the field of coverage of the BS.
- The first enhancement layer is coded using 16QAM, the corresponding data burst will be visible only to SS1 and SS2. (i.e., only stations that can decode this modulation)
- The second enhancement layer is coded using 64QAM; the corresponding data burst will be visible only to SS1.

In this example, we note that each SS receives a different video quality. The video segments are encoded with modulations in descending order of strength. More redundancy is omitted and the resources are used much less. The resources released can be used to improve video quality for all SSs. For example, the coding of the base layer and first enhancement layer may be made in QPSK and hence the opportunity for SS3 to receive enhanced video quality. Specifically, we modify the admission control function at the BS to determine the optimal distribution between multicast groups and different modulations used in the cell. This is to maximize the video quality received by each SS based on the available resources in the radio channel. The algorithm for allocating resources to different video streams can be described as follows:

- Perform the list of SSs wishing to receive the video stream.
- Establish respectively the modulation schemes of SSs in descending order of strength.
- List the flows of services related to multicast groups according to the size of the transported video layer.
- Calculate the number of slots required for each physical flow of service with each modulation.
- To maximize the number of SSs receiving the video stream, the BS assigns the most robust possible modulation to all streams of service as allowed by the available resources.
- If the resources are exhausted and there is still another layer to improve video that has not yet been transmitted, the BS needs to change the modulation of one or more previous layers to a less robust modulation in order to free up resources for new flows. The new stream will be encoded with the least robust modulation already used. Note that this change does not affect IP multicast.

In the best case, all layers of video are encoded using the most robust modulation and thus all SSs receive the same video with better quality. The worst case is when the resources available do not allow the transmission of video streams with the least robust modulation and thus only a small number of SSs will have access to the video. Multi-mode modulation benefits from the diversity of patterns of modulation of SSs part of the same cell, and the diversity of groups representing the multicast SVC video layers. The ideal combination of these two parameters, taking the available resources into account, allows the BS to distribute video streams to different SSs in a fair and optimal way.

The next section describes another technique introduced to save considerable resources. Unlike the multi-mode modulation, this technique allows each SS to use a single modulation scheme pre-negotiated between the SS and the BS.

4.3.3.3. Superposition coding scheme. According to IEEE 802.16, the result of scheduling at the BS is to allocate resources for each service flow for each SS. The allocation information is transmitted via the DL_MAP message to all SSs. Each SS has the location of the burst data in the frame. The burst of data allocated to it is encoded with the most appropriate modulation according to its radio condition. Since it is destined to other SS, the rest of the burst can be encoded with a different modulation.

Let us consider the topology depicted in Fig. 10, with the SVC server and SSs with different modulations. Usually, multiple data bursts will be created each with a different modulation according to SS destination. Each SS receives its data in the burst intended to it, and remains idle during other bursts carrying the other streaming video/data to other SSs. If multiple SSs with different modulations could use the same burst of data, a considerable gain of radio resources can be achieved. Indeed, if the BS reaches coding of OFDM symbols with two or more modulations at the same time, each SS decodes these symbols with OFDM modulation and recovers its own data. This technique is called superposition coding (She et al., 2007, 2008) and was designed to improve the user capacity in wireless networks. An example is illustrated in Fig. 11. The nodes are indexed in ascending order according to their distance from the BS. As shown, when the BS transmits a signal to M3 with a certain SNR level, the SNR experienced by both M1 and M2 is either greater than their expected level of SNR or sufficient. Similarly, when the BS

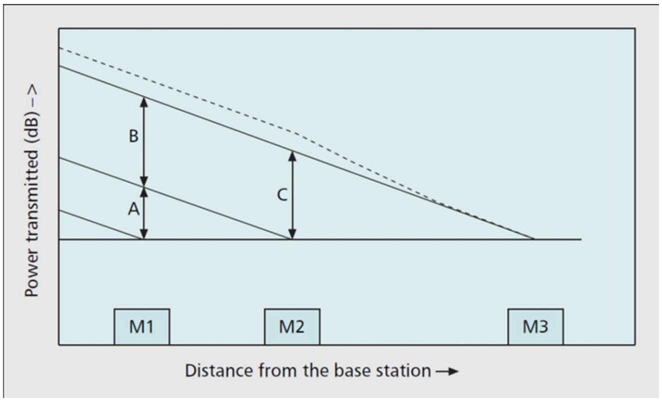

Fig. 11. Superposition coding in cellular network (She et al., 2008).

transmits a signal to M2, M1 receives extra power above its SNR level. This implies that M1 has a sufficient SNR to decode messages intended for both M2 and M3, and M2 has a sufficient SNR to decode messages intended for M3. Thus, information intended for M1 can be included in the transmission of M2 to M3 using superposition coding. Similarly, the information for M2 can be included in the transmission to M3.

The use of superposition coding in the context of SVC multicast transmission is as follows:

- Perform the list of SSs wishing to receive the SVC video stream.
- Establish respectively the different modulations of SSs in descending order of strength.
- List the flows of services related to multicast groups according to the size of the transported video layer.
- Calculate the number of slots required for each physical flow of service with each modulation.
- Depending on the number of available physical slots, calculate for each modulation, the maximum flow of service beginning with the most important.
- Use superposition coding by overlaying data from different modulations.

This algorithm is included in the admission control function at the BS, similar to the previous solution. To limit the number of superposed modulations, the BS should choose two or three modulations most suitable to meet the maximum SSs of the cell. Note that, unlike the multiple modulations mode, redundancy is still present in the overlay technique. For example, the base layer is encoded as many times as there are modulations to superpose. This is due to the fact that the SS can decode several modulations simultaneously. Despite this redundancy, the amount of used resources remains less than any other proposal.

5. Performance evaluation

In this section, we evaluate through simulations the performance of the two proposed solutions and compare the results with the conventional method in terms of the obtained gain.

5.1. Unicast services support

We consider the same topology as in Fig. 3, the link between BS1 and BS2 is assumed to be a reliable wired link since we focus essentially on the WiMAX network performance. We use QualNet Network Simulator (SNT, Online), which implements the PMP (point to multipoint) mode of IEEE802.16, and in which we implemented our XLO. We set IEEE 802.16 PHY parameters as mentioned in Table 1. We simulate a video streaming traffic from SS2 to SS4 with different scenarios using video traffic generator based on pre-encoded MPEG-4 traffic traces (MPEG-4 and H.263, Online). These traces provide three video qualities: high, medium and low video quality corresponding to three different data rates (see Table 2 for more details). We developed a new scalable video streaming generator based on MPEG traces which is capable of stream switching by varying video quality and consequently varying video data rate. In the next subsection, we describe four simulated scenarios and discuss the simulation results.

5.1.1. Scenario 1: normal conditions

This first scenario evaluates the throughput of video streaming under normal condition, and assuming there are enough resources in the network. Figure 12 shows the simulation results for high, medium and low video quality. The obtained bit rate for each quality is indicated by the Y axis. These curves will serve as a baseline for better understanding of the subsequent scenarios.

5.1.2. Scenario 2: admission control adaptation

In this scenario, we evaluate the performance of the proposed solution in the presence of an admission control mechanism.

Table 1
IEEE 802.16 PHY simulation parameters.

Propagation channel frequency	2.4 GHz
Channel bandwidth	20 MHz
FFT size	20 48
Antenna gain	12 dB
Transmission Power	20 dB
Frame size	20 ms

Table 2
High, medium and low video quality.

	Video quality		
	High	***Medium***	***Low***
Frame rate	25 frames/s	25 frames/s	25 frames/s
Mean data rate	766 kbps	267 kbps	153 kbps

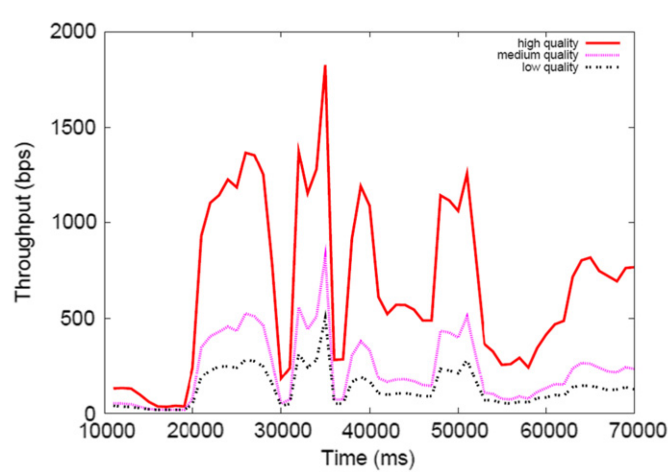

Fig. 12. High, medium and low video quality data rate.

In addition to our scalable video traffic from SS2 to SS4, we added background traffic from SS1 and SS3 to SS5 with higher priority to disrupt video traffic. We choose real time CBR traffic with a high bit rate so that BS1 will not have enough resources to satisfy high video quality and force the video streaming server via the XLO to reduce its data rate until satisfaction as explained in Fig. 5. Background traffic runs during all simulation time, and video streaming traffic starts at t=10 s for one minute long. Table 3 indicates background traffic data rate in each scenario. By default, the video streaming server starts transmitting with high video quality and keeps XLO adapting its data rate according to BS feedbacks. In Fig. 13, we can observe how the application switches immediately from high to medium quality with only few packets belonging to high video quality, and then the curve takes the shape corresponding to the medium quality. The same behavior is observed in Fig. 14 where XLO moves the video quality down to a lower level. In fact, CBR traffic data rate is high enough (30.75 Mbps) so that BS1 has no longer available resources to satisfy high or medium quality.

5.1.3. *Scenario 3: adaptation during video streaming (decrease of video data rate)*

This scenario aims at showing how XLO works during the lifetime of the video streaming session. We simulate the same configuration as in the precedent scenario. CBR data rate is chosen so as to give high video quality the chance to be accepted from the beginning of the streaming session. Then, at $t=30$ s, we initiate another CBR traffic with higher priority. We manage its data rate so that the BS will not have enough resources for already existing video traffic. The total data rate of background traffic is shown in Table 3. We simulate this scenario without XLO, and we obtain the results shown in Fig. 15.

We can see that with no XLO, when the BS cannot satisfy the high quality video data rate, a reject message is sent to SS2, the SF connection aborts and the video streaming traffic is simply interrupted while with XLO the results are different. Thanks to our optimization of its scheduling algorithm, the BS is aware of SFs related to scalable video streaming application. Consequently, as shown in Fig. 6, XLO will force the video streaming server-side application to adapt and reduce its data rate. Figure 16 shows the

Table 3
Scenarios background traffic settings.

Description	Background CBR traffic data rate	Related figures
Scenario 2		
High reduced to medium quality in admission control	30.6 Mbps	Fig. 13
High reduced to low quality in admission control	30.75 Mbps	Fig. 14
Scenario 3		
High reduced to medium quality during video streaming session	30.6 Mbps	Fig. 16
High reduced to low quality during video streaming session	31 Mbps	Fig. 17
Scenario 4		
Low increased to high video quality during video streaming session	30.75 Mbps ends at 40 s	Fig. 18

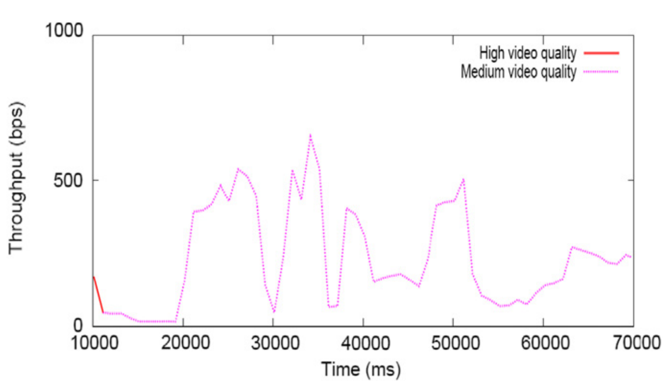

Fig. 13. High quality reduced to Medium quality video data rate in admission.

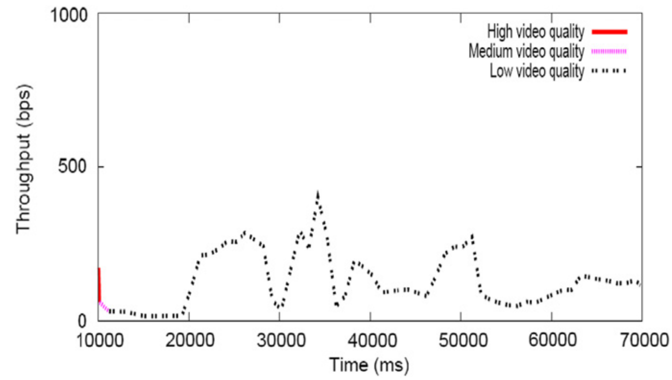

Fig. 14. Reduced to low quality video data rate in admission.

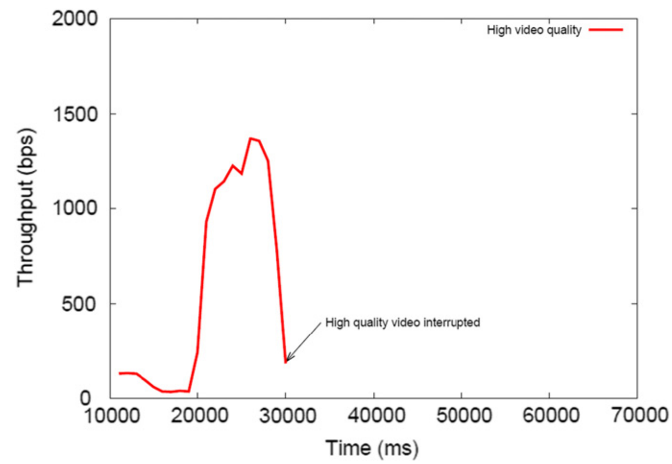

Fig. 15. High quality video data rate interrupted during transmission (without XLO).

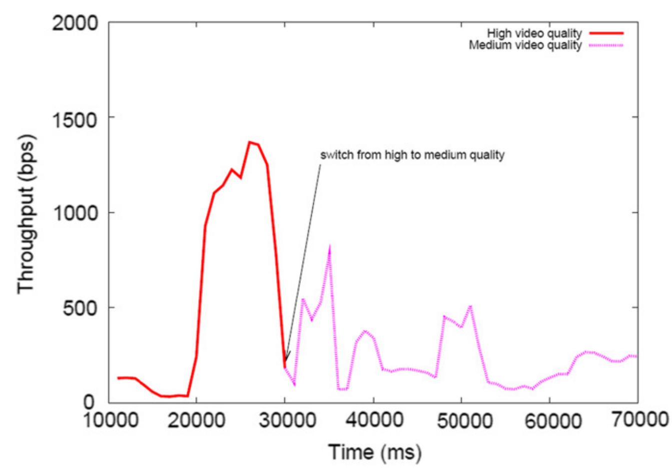

Fig. 16. High reduced to medium quality video data rate during transmission.

simulation results for a scenario where video data rate is reduced to the data rate of the medium video quality. Figure 17 shows simulation results for a scenario where video data rate is reduced multiple times until it reaches a low video quality.

5.1.4. Scenario 4: adaptation during video streaming (video data rate increase)

In this scenario, we use the same simulation settings as in scenario 2 with a background traffic of 30.75 Mbps starting at the beginning of the simulation but ending at $t=40$ s and not during all simulation time. As mentioned above, the video data rate will decrease, thanks to XLO admission control, until it reaches a low video quality. Then, at $t=40$ s, background traffic stops and the resources it used become available. When the XLO entity detects such resource availability, it informs the video streaming server in order to increase its video data rate. A first DSC request message is sent from SS to BS to reach medium video quality as mentioned in Fig. 17, and then a second DSC request is sent to reach high video quality (Fig. 18).

5.2. Multicast services support

In this set of simulations, we first evaluate the classic case of SVC multicast transmission in WiMAX networks without any modification. Then, a first approach is implemented which maps multicast groups to different modulation patterns. Finally, we evaluate the SVC multicast transmission with a superposition coding.

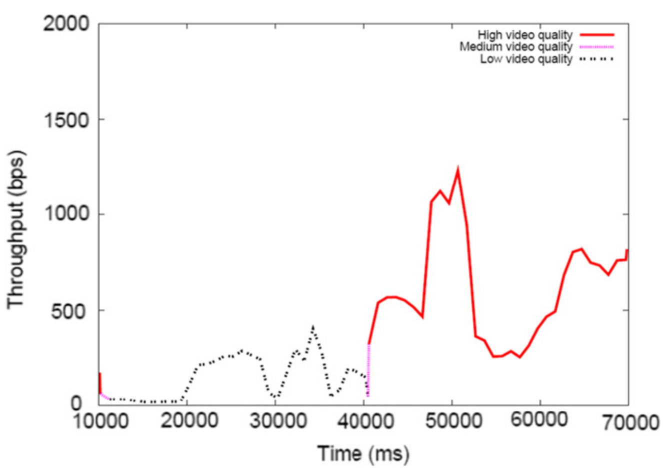

Fig. 17. Low quality increased to high quality video data rate during transmission.

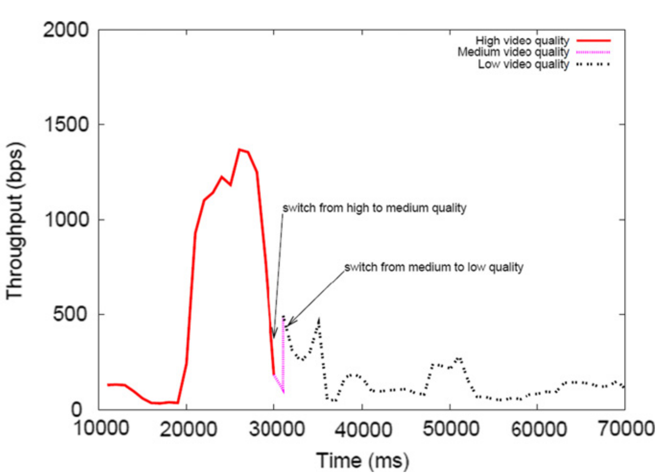

Fig. 18. High reduced to low quality video data rate during transmission.

5.2.1. Simulation environment

The implementation is divided into two parts:

- *The SVC multicast server*: We adapted a traffic generator QualNet already set to generate multiple streams, each corresponding to a video layer from a SVC traffic trace file. These traces represent the sizes of images, and the transmission time of each image. With the help of a program using the JSVM tool, we obtain log files from a real video coded using SVC. These traces contain in particular the size of images and their membership base layer or enhancement layers. The multicast stream is transmitted as an SVC video layer.
- *Admission control*: we have changed the resource allocation algorithms in the BS admission control function. New features are added to support SVC multicast video traffic. Two versions were implemented: one for multi-mode modulation that provides the best distribution between the modulations and multicast groups, and the second for the superposition coding to determine the number of video layers required for each modulation. For both versions, the signaling between the BS and the SSs is provided by the DL_MAP_IE MAP fields sent at the beginning of each frame.

The parameters of the IEEE 802.16 physical layer, common to all BSs in all simulations are provided in Table 4. The used parameters of the SVC video are provided in Table 5. The 60-s video sequence is partitioned into several video layers: a base layer L0 and four enhancement layers L1, L2, L3 and L4.

5.2.2. Simulation results

We perform a first set of simulations using a topology with three WiMAX cells connected through a wired network (Internet or LAN) to the SVC video server (Fig. 19). A SS of each cell should receive the maximum video quality. In the first scenario, no changes at the BS are applied. The BS operates in classic mode as defined by default in the QualNet simulator.

We do not distinguish between SSs in terms of radio characteristics during scheduling. To do so, the 3 SSs are placed at the same distance from their BS, as shown in Table 6. However, a

Table 4
Phy layer simulation parameters.

Propagation channel frequency	2.4 GHz
Channel bandwidth	20 MHz
FFT size	2048
Antenna gain	12 dB
Transmission Power	20 dB
Frame size	20 ms

Table 5
SVC parameters.

Description	Soccer sequence
Duration	60 s
Average throughput	~ 160 Kbps
GOP Size	16 images par GOP
Number of video layers	5 (noted L0, ..., L4)
Average throughput for	
L0	~37 Kbps
L1	~17 Kbps
L2	~28 Kbps
L3	~38 Kbps
L4	~40 Kbps

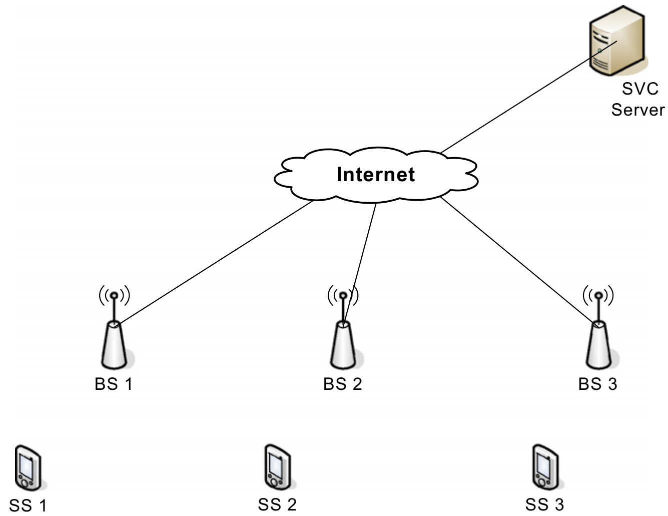

Fig. 19. Multiple cells topology.

Table 6
Identical SS in different cells scenario.

	SS 1	SS 2	SS 3
Distance from the BS (m)	350	350	350
CBR flow (Mbps)	19.97	19.90	0

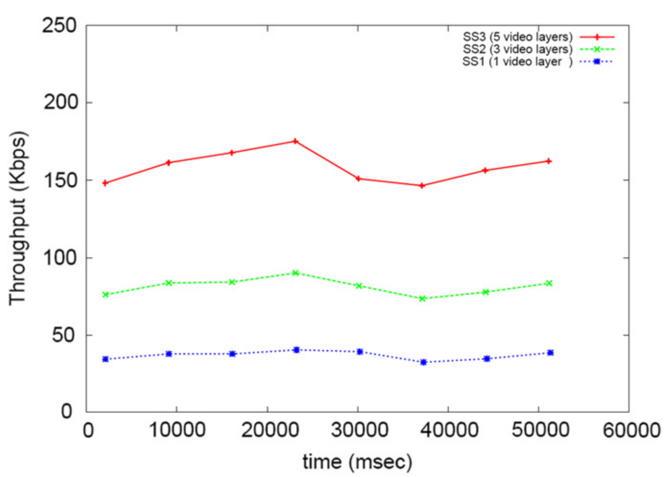

Fig. 20. Identical SS in different cells scenario.

difference exists between the SSs and the traffic present in each cell is not the same. CBR traffic is added in the background to overload the cell. We modify the flow of traffic in each cell to observe its influence on the multicast SVC video traffic.

Note that the CBR flow is added with a higher priority than SVC flow, the goal is to limit bandwidth in each cell to force the SS to select a lower video quality. The results of this simulations are illustrated in Fig. 20.

We note that the three SSs do not receive the same quality video. SS1 has the lowest quality by receiving the base layer L0 only, all resources being allocated. The BS was unable to allocate more bandwidth to SS1. The highest video quality is perceived by SS3 which receives the 5 layers of video (L0 to L4) with no traffic disturbance (all the resources of the BS were available to SS3). Finally, SS2 receives a medium quality video containing the base layer L0 and two enhancement layers L1 and L2. This simulation result validates the usefulness of the decomposition of SVC flow into several multicast groups. Each SS, depending on the available bandwidth, acquires a different video quality. In addition, multicast groups, containing layers of unnecessary improvements, are not transmitted to the BS; their flow stops at the last router in common with other BS.

The rest of the simulations described in this section are made with the topology illustrated in Fig. 21. This topilogy includes a single cell WiMAX and 3 SSs placed at different distances from the BS. The distances of SSs are chosen so that the modulations assigned to them are different from each other as shown in Table 7.

Three scenarios are defined. First, we conduct a simulation in the simple modulation mode without any modification; then we simulate the multi-mode modulation; and finally, we simulate the superposition coding mode. In all three simulation sets, we keep the same parameters of 802.16 physical layer and the same simulation parameters such as the distance of their SSs to the BS. In addition, a background CBR traffic with a high priority is introduced in all simulations. In order to effectively compare the different proposals, we assume in each simulation scenario, that the BS has the same radio resources to serve the present SSs.

5.2.2.1. Simple coding scheme. In the simple coding mode, each SS receives the data with the modulation assigned by the BS. In order to serve all the present SSs, it is necessary that the layers L0, 1, 2, 3 and 4 are coded with the three modulations QPSK, 16 QAM, and 64 QAM. For this, the BS must allocate the necessary resources for 15 data bursts. Precisely, we chose the flow of CBR traffic (19.8 million bps) to prevent this from happening. Indeed, the BS is unable to satisfy all the SSs. The results of these simulations are depicted in Fig. 22.

We note that none of SSs could reach the optimal video quality. Indeed, SS1 reached an average rate of about 80 kbps, which corresponds to the average flow layers L0, L1 and L2 combined. SS2 and SS3 received L0 and L1. By analyzing the log files, we found that the resources available to the BS were used as follows:

- The L0 layer coded QPSK for SS3, in 16QAM and 64QAM for SS2 to SS1.

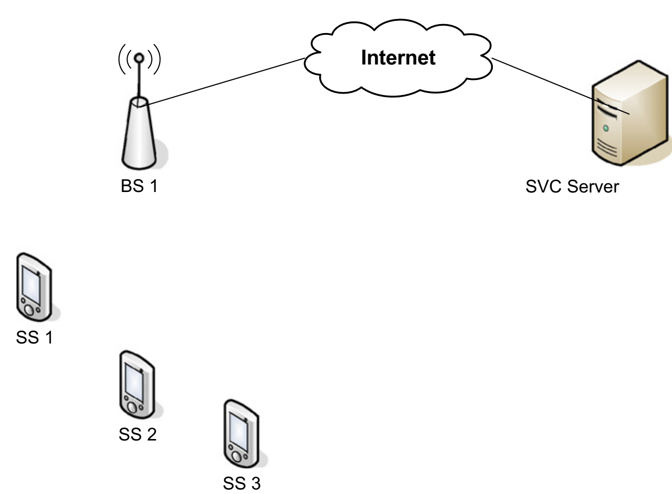

Fig. 21. Different SS in the same cells scenario.

Table 7
Different SS in the same cell scenario.

	SS 1	SS 2	SS 3
Distance from the BS (m)	100	350	580
CBR flow (Mbps)	19.80	19.80	19.80
Modulation/coding rate	64QAM	16QAM	QPSK

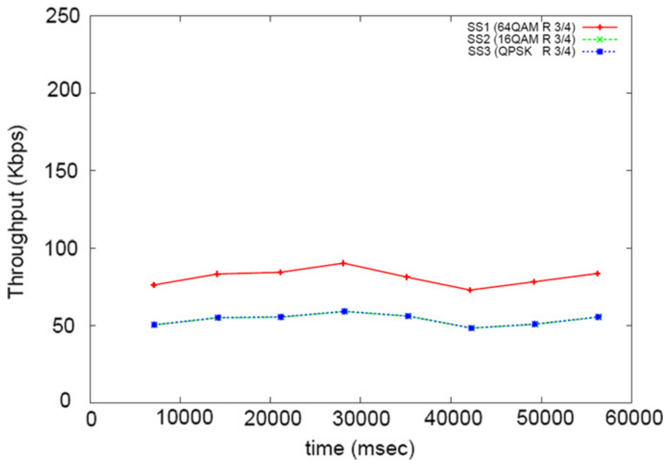

Fig. 22. Simple coding scheme scenario.

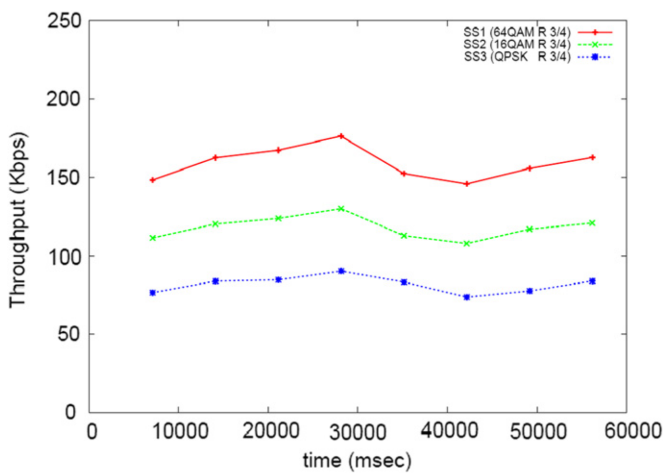

Fig. 23. Multiple coding scheme scenario.

- The L1 layer coded QPSK for SS3, in 16QAM and 64QAM for SS2 to SS1.
- The layer L2 coded 64QAM for SS1.

These simulation results suggest that the multicast transmission has not been beneficial to the three heterogeneous SSs since there were redundant layers L0 and L1. In the next scenario, we perform the needed changes to optimize the utilization of available resources.

5.2.2.2. Multiple coding scheme. In this scenario, we perform the simulations with the same parameters as in the previous one. The results are illustrated in Fig. 23. With the optimized use of modulations, the SSs are able to improve the quality of their videos. Indeed, SS3 reached a rate equivalent to 3 video layers instead of only two layers in the basic mode. SS2 acquires two additional enhancement layers and SS1 manages to have the maximum video quality. The minimum video quality in this scenario is the best video quality achieved in the classic mode, this represents a considerable gain.

The simulation traces of the physical layer of the BS provide us with the following information: layer L0, L1 and L2 were coded in QPSK and 16QAM whereas L3 and L4 in 64QAM. Thus, three bursts with three modulations are inserted into the frame. Therefore, each SS is able to decode the burst with the modulation assigned by default, and the burst with a more robust modulation as the modulation by default. It is then the role of the BS to inform the SSs about the burst availability. In addition, no redundancy is introduced, i.e., each video layer is encoded once and with a single modulation. Resources became available, compared to the simple coding mode, which allows the addition of other video layers and hence improves the video quality in each SS.

5.2.2.3. Superposition coding scheme. In this scenario, we use the same parameters as in previous scenarios. The simulation results of the superposed coding scheme are provided in Fig. 24. We notice a significant improvement. The average flow of the video stream observed in each cell is significantly higher than in other scenarios. Indeed, SS1 and SS2 reach the maximum quality of the video (all layers), SS3 receives 4 video layers (only a single enhancement layer is missing).

At the physical layer, the resources were allocated as follows: for each SS, the BS allocates a burst of data encoded with the default modulation used by the SS. Three bursts in total are allocated where the size of each burst must not exceed the number of the available slots in the physical frame independently of the modulation used. In our simulation, it is clear that the number of physical slots available is smaller than the number of slots required for a burst that contains all the video layers and encoded with QPSK. For this reason, SS3 received four of the five layers. For the burst encoded in 16QAM and 64QAM, it was possible to transmit the 5 layers.

The results of three scenarios are summarized in Table 8. The table shows the number of video layers received by each SS in every scenario. We note that the conventional method fails to satisfy any SS with a maximum video quality while the BS has allocated all the available resources. The multiple modulations mode provides a considerable gain and the optimized use of modulation schemes for each SS demonstrates its effectiveness. This mode offers the best SS quality observed compared to the classic mode. Finally, the superposition coding represents the highest utilization of radio resources compared to all scenarios.

The two methods we presented are suitable for the disadvantageous SSs, i.e., those at the farthest distance from the BS. Indeed,

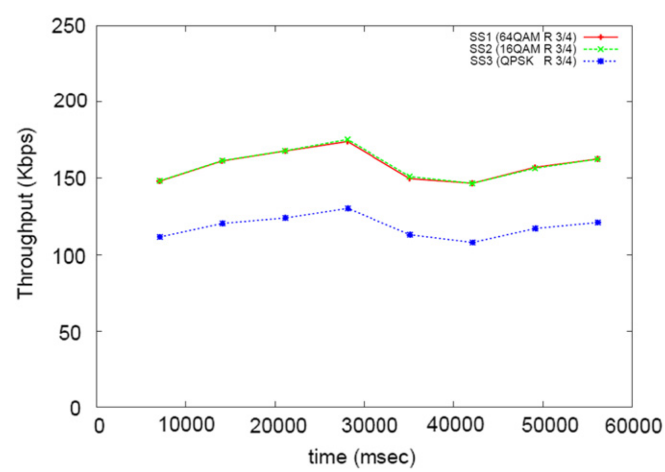

Fig. 24. Scenario: superposition coding scheme.

Table 8
Number of video layer received.

	SS 1	SS 2	SS 3
Superposition coding	5	5	4
Multiple modulations	5	4	3
Simple modulation	3	2	2

we note that SS2 and SS3 are those which benefited the most from the optimization since both proposals provide them with a quality approaching the maximum.

6. Conclusion

This paper introduced a cross layer approach for adaptive video streaming applications in IEEE 802.16 networks for both unicast and multicast traffic. For unicast traffic, we developed the XLO optimizer which collects information provided by the MAC layer, essentially SF management messages exchanged between BS and SS and assigns new optimized parameters to the video streaming server-side application. The pursued goal in this case is to adapt video data rate according to the resource availability at the MAC layer. The conducted simulations showed that adaptation can be performed during the admission control process and the lifetime of video streaming sessions and allows a continuous video stream with no interruption especially if there are no available resources for the high video quality. Our future work in this context includes the extension of the current optimizer to multi-hop relay WiMAX networks. Furthermore, the cross layer optimization described in this paper follows a bottom-up approach where the applications benefit from lower layers parameters. It will be interesting to complement it with a top-down approach to make the MAC layer adaptable to video application requirements. For multicast support, we seeked the best compromise between, on one hand, the heterogeneity of client stations in terms of bandwidth resources and channel conditions, and on the other hand, the hierarchical structure of SVC video coding system suitable for heterogeneous receivers. We studied the operation of such applications in a typical WiMAX network, identified the inherent problems and proposed solutions to address them. Specifically, two techniques were introduced. First, an intelligent use of different modulations at the SSs yielded a significant gain in terms of resource usage. Second, coding using multiple modulations allowed for an optimal use of the resources available in the cell. The principle underlying this technique lies in the fact that the radio bearer, when sending data to a station far from the BS, allows the integration of data sent to a nearby station at the same time. Optimizing resource utilization remains a promising research topic. The mechanisms described in this paper are tailored for the IEEE 802.16 OFDMA physical layer. The decomposition of the frame into several OFDM symbols or physical slots allows multiple users to access the channel and creates, therefore, opportunities for devising more effeicient scheduling and resource allocation algorithms.

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